

## Investigation of Cyclic $O-C$ Changes in a Sample of Eclipsing Binaries

Damian Jableka<sup>1</sup>, Staszek Zola<sup>1,2</sup>, Reed Riddle<sup>3</sup>, Christoph Baranec<sup>3</sup>, and Nick Law<sup>3</sup>

<sup>1</sup>*Astronomical Observatory of the Jagiellonian University, Cracow, Poland;  
jableka@oa.uj.edu.pl*

<sup>2</sup>*Mt. Suhora Astronomical Observatory, Cracow Pedagogical University,  
Cracow, Poland;*

<sup>3</sup>*California Institute of Technology, Pasadena, California, USA;*

**Abstract.** In this work we present an analysis of cyclic or pseudo-cyclic  $O-C$  behavior in a sample of 29 eclipsing binaries, selected to exhibit large-amplitude changes in  $O-C$ . We attempt to explain the period variations by: 1) the light time travel effect due to an unseen third body orbiting a system; 2) a sudden jump in the linear ephemeris caused by either variations in the mass transfer rate or CME ejections. A search for tertiary components was carried out with adaptive optics imaging for six systems exhibiting the highest amplitude in their  $O-C$  diagrams.

### 1. Introduction

Two main ideas can explain the observed periodic variation in the timing of minimum of eclipsing binary systems: 1) the presence of a third, unseen companion (Irwin 1959), or 2) a change in the star shape due to magnetic activity (Applegate 1992). The vast majority of systems display some trend in their  $O-C$ s. In this work we show a comparison between fitting their  $O-C$ s by the light time travel effect (hereafter LTTE) and a combination of few linear ephemerides (hereafter FLE). To do this, we have chosen 29 binaries whose  $O-C$  diagrams exhibit cyclic orbital period variations (see details in Jableka et al. 2013). The six systems from our sample that show the largest  $O-C$  amplitudes have been observed with adaptive optics.

### 2. Third Body Model and Few Linear Ephemeris Fitting

A model consisting of nine parameters is needed for the LTTE model. Such a large number of degrees of freedom and correlations among parameters makes finding of the global solution a challenge. We have applied the Monte Carlo algorithm, which is capable of finding the global minimum and does not require any initial parameters. Once the best solution for each system was found, we computed the third body mass function and the lower mass limit. The resulting third body masses vary from  $1.29 M_{\odot}$  to  $18.83 M_{\odot}$ , with a median of  $2.34 M_{\odot}$ . All systems examined have relatively tight configurations with periods ranging from 1 to 6 days, in most cases. This means that

both mass transfer between components and mass flow in these systems are possible. Mass transfer causes a continuous period lengthening or shortening, which can be seen as a parabolic shape in the  $O - C$ s. In 18 out of the 29 cases examined we found a significant quadratic term. A steady mass loss caused by a strong stellar wind produces the same effect on in the  $O - C$  diagram as mass transfer, but if mass is lost or accreted suddenly, then a sudden jump in the binary period may occur and this will be seen in the  $O - C$  diagram as a sudden shift from one linear ephemeris to another. For 27 systems we fitted 2–6 linear ephemerides and calculated the mass gained or lost, as in Li & Zhang (2006). The estimated mass gained or lost as a result of each linear ephemeris break varies from  $8 \times 10^{-8} M_{\odot}$  to  $2.1 \times 10^{-4} M_{\odot}$ , with a median of  $6.7 \times 10^{-7} M_{\odot}$ . Before fitting the FLE model we subtracted the quadratic term from the  $O - C$  data, as in the case of LTTE. For each system we compared the sum of the squares of the residuals and the standard deviations for both fitted solutions. For 10 systems the sum of the squares of the residuals of the LTTE fit is smaller than in the FLE fit, while in the remaining 17 cases a better solution was derived for the FLE model.

### 3. Adaptive Optics Observation

We used the Robo-AO adaptive optics instrument at the Palomar 60-inch telescope (Baranec et al. 2014) to examine closely 6 systems with the largest  $O - C$  amplitudes. Only one of the six systems considered (RW Per) shows significant additional light. We measured the peak-to-peak separation to be 172 mas, which gives a linear distance to the third component of  $52 \pm 13$  au. On the other hand, the  $O - C$  amplitude of 0.11 days corresponds to a linear distance of  $20 \pm 6$  au. The ratio between these distances is around 2.7, which corresponds to a high inclination. However, it should be noted that the absolute parameters and distance to RW Per are not accurately known. Nevertheless, it is promising that we obtain the same order of magnitude for both distance estimates.

### 4. Conclusion

The solutions with more than one linear ephemeris gave better results in more cases than the third body solution. In each system we may be dealing with a mixed scenario. If we assume that breaks in the linear ephemerides are caused by mass ejection from the system produced by strong protuberances, then a strong magnetic field is required, and such a field can also support the idea of changes in shape as in the Applegate mechanism. The FLE model requires some mechanism for the accretion of matter onto the system from the surrounding area. Fits of similar quality may also result from very uneven data coverage, which can favor a linear fit rather than a sine-curve fit. Direct imaging to search for third bodies using adaptive optics appears to be very promising but requires further investigation.

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### References

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Conference hall during the meeting.